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Abstract— **Main contribution of Ukrainian scientists to radar is analized. It is shown that radar field was seriously developed in Ukraine since the very first works in 30s of last century up to nowadays. Radar theory and technology in Ukraine was developed by efforts of experts from universities, academy of scienses, specialized research institutions, and industry.**

Keywords—radar; signal processing; antennas; history of radar; radar developments

I. Introduction

Maxwell theory, experiments by H. Hertz, wireless communications over Baltic Sea by A.S. Popov, foresight articles and lectures by N. Tesla, G. Marconi wireless devices and some other achievements can be considered as the forerunners of the radar. But the first working device that directly implemented the principle of active monostatic radar was built by Christian Huelsmeyer to identify ships at a distance. It was patented in 1904 in Germany and Holland and named 'telemobiloscope'. The Huelsmeyer's invention had no commercial success then, and it was pretty quickly forgotten.

The creation of modern radar was gradually prepared by the general level of science & technology and the needs of society. Only in the thirties of XX century, the technical and economic, as well as social and military conditions appeared for the development of practical means of radar. Almost simultaneously and independently researches on the creation of radar devices were started at least in Great Britain, USA, Germany, Italy, Japan, France, the Netherlands, Hungary, and the Soviet Union (USSR).

Ukraine was one of the most technically advanced republics of the USSR. It even had some attributes of independency like its own constitution and the formal right to secession, which, of course, was impossible to implement in practice. Ukraine was also a member of the UN since the founding of this organization. However, before the collapse of the USSR in 1991, Ukrainian scientists were involved in the overall development of science and technology of the USSR. Many immigrants from the Ukraine worked on development of modern electronic technology in different organizations in Moscow, Leningrad (Saint-Petersburg) and other Russian scientific centers. However, in this paper we consider exclusively those achievements that have been received by scientists, experts and organizations that were located only directly on the territory of Ukraine.

Despite the fact that the content of this article was discussed with many colleagues, this work does not pretend to be a full and complete display of the history and achievements of the radar in Ukraine. Moreover, radar , being a synthetic field of science and technology, has incorporated advances in the theory and technology of antennas, radio waves propagation, transmitters and receivers, signal processing, automatic control, information display, etc. It is impossible to pay appropriate attention to all these issues in one paper. History is not an exact science, and this paper only summarizes the information known to the author from the literature as well as from personal communication with some of direct participants of this hard and long process of radar development. Following to the advice of Prof. Yakov Shifrin who today is, perhaps, the oldest scientist contributed significantly to radar in Ukraine, we divide the process of radar development on five stages below.

II. The Very First Works During 1920-1941

A. Creation of powerful UHF generators

One of the key engineering prerequisites for implementation of the radar idea was to create powerful microwave generators. The research in this field was initiated in Ukraine in the 1920s at the Kharkov National University (KhNU). In 1924, A.A. Slutskin (1881-1950) and D.S. Steinberg (1888-1934) studied the processes in electronic valves under the action of external magnetic field. This led to creation of powerful generators of magnetron type [1, 2]. As was described in [3], in 1924, they succeeded in generating magnetron oscillations with 7.3-cm wavelength. By the end of the decade, these studies were leading in the world in this field. After 1929, this work was greatly expanded and intensified when the Ukrainian Institute of Physics and Technology (UIPT, now The National Scientific Center—Kharkov Institute of Physics and Technology – NSC-KhIPT) was established in Kharkov, then the capital city of Ukraine (till 1934). There, Abram Slutskin obtained his second job, as a head of the Laboratory of Electromagnetic Oscillations (LEMO). His team designed and studied both CW and pulse magnetrons of different versions: water-cooled and not cooled, in glass and metal cases, etc. In 1933 the problem of excitation of powerful UHF oscillations in magnetrons with a split cathode and control their output power and frequency was solved [3, 4].

B. *First three-coordinate radar 'Zenit'*

Based on the successful generator development, in 1935 A. Slutskin started an ambitious project, developing the first-ever three-coordinate L-band pulse radar with an operating wavelength of 60 cm. At that time, existed systems were able to determine only two target coordinates. By the end of 1936, the team of LEMO UPTI (A.A. Slutskin, A.Ya. Usikov, and S.Ya. Braude) started a complex work of creating L-band pulse radar for anti-aircraft artillery [5]. In 1938 the radar prototype was designed, fabricated, and tested; the first experiments on the detection of airplanes were carried out. The State Committee, giving an overall assessment of this device, indicated that in Ukrainian SSR first in the USSR the radar prototype has been developed that making it possible to determine the three coordinates (range, azimuth and elevation) of aircraft in the air. It was a two-antenna radar system.

Unfortunately, the purges that smashed UIPT after 1937 slowed down the work. Then WWII and the first defeat of Red Army in Ukraine disrupted the plans, and no radar was put into serial production [3]. Before Kharkov was lost, the LEMO team had been evacuated to Bukhara (Uzbekistan).

III. PERIOD OF THE II WORLD WAR SINCE THE OCCUPATION OF UKRAINE

During the WWII, the territory of Ukraine was completely occupied by the end of 1941. Only those scientists and laboratories that were evacuated to the East, had a possibility to do research and design work. A typical example was the activity of LEMO UIPT team in Bukhara, where it managed to design a single-antenna pulse radar [5] with advanced characteristics that was later used for sea and air surveillance near Moscow and in the Arctic region [3]. That was the time when the first practical military applications of radar were really important. It is interesting that alongside with development of the radar in Bukhara, the scientists of evacuated UIPT discovered an unknown earlier phenomenon of a very long-distance propagation of electromagnetic waves of L-band over the surface of desert [6].

According to the recollections of Professor Shifrin, with the gradual liberation of Ukraine, on its territory the antiaircraft batteries participated in hostilities; and also the control-repair shops that provided maintenance and repair of radar equipment. Yakov Shifrin, who in the future contributed significantly into the theory and practice of antennas [9], commanded by antiaircraft battery that was established in October 1944 in Mogilev-Podolsky. Such batteries were armed with radars including American SCR-584 and others. After the liberation of Kiev, the Headquarter of anti-aircraft defense of the Southwestern Front was located in the highest part of the Kiev-city; it had the radar branches, and Yakov Shifrin served there during some time.

IV. THE POSTWAR PERIOD: 1945-1955

This period is characterized by the creation of many new military and civilian research institutes in Kiev, Kharkov and other cities, including of radar profile. UIPT was returned back to Kharkov. The works on overhorizon radar were started there using decameter and hectometer waves. The researches in wave propagation over the sea surface were fulfilled, and the unique breadboards of overhorizon radars have been created at wavelength of 10.5, 23, 53, 115, and 240 m that were successfully used in experiments [5]. The results showed presence of intensive clutters from ruffled sea-surface especially at shorter wavelengths, and the basic works were conducted in 115 and 220 m wavelengths. In 1952, S.Ya. Braude et al were awarded by the State Prize for this circle of works.

Some new military schools of radar profile were created, particularly Military Academy of Artillery Radar (1946), later Artilery Radio-Technical Academy of soviet army (ARTA) in Kharkov, where Yakov D. Shirman began to work. In number of military and civilian institutions the radar courses began to be introduced. During this same period, broad circles of radio-engineering experts were able to read the books of famous MIT series that were translated into Russian. In these books the invaluable UK and American experience in the development of radar technology during the WWII has been generalized.

Original textbooks in radar were also started in USSR, particularly in Ukraine SSR. Gradually the section "Principles and Methods of Radar" of the course on "Theoretical Fundamentals of Radio-engineering and Radar" that was delivering in ARTA by G.N. Shein and Ya. D. Shirman was becoming deeper (in 1949 it was just 20 hours) [7]. Deepening of teaching the issues of MTI in the lectures helped Yakov D. Shirman to understand and suggest the transition from the Single Delay Line Canceler to Double- and Multiple- Delay Line Canceler. In 1951 he was awarded by the invention patent (author certificate) No 13855 on MTI system with multiple delay line canceler. This invention was very quickly implemented in radar P-12 and then anti-missile system C-75 and other systems [7].

V. INTENSIVE DEVELOPMENT OF RADAR IN UKRAINE DURING 1955-1990

This was the heyday of radar science in ARTA (another name VIRTA), in Kharkov Aviation Institute (today Kharkiv National Aerospace University "KhAI"), in the Usikov Institute of Radiophysics and Electronics (IRE NASU), Odessa Politechnic Institute, Kiev Institute of Civil Aviation Engineers (today National Aviation University - NAU) and many other institutions. During these years, many fundamental monographs, textbooks and articles were written. Great number of radar experts was prepared in numerous military and civilian universities in Ukraine. Many research and design projects were made on the development of radar technology.

In ARTA (VIRTA) the school of Yakov D. Shirman worked very effectively. Some important results are reviewed in [8]. The invention by Shirman in 1955 of the wideband-pulse compression in matched filter was one of the most significant contributions to the theory and technique of radar. It was done independently and practically in the same time as in USA, and it was implemented by much more sophisticated and effective way. The first purpose of this invention was the overcoming of the contradiction between improving range resolution and increasing range of detection. Moreover, it was

also the beginning of the works on the theory of Time-Frequency Resolution and Theory of Space Resolution (1958-59). In the beginning of 1960s the new scientific direction "Statistical Radar" was in fact was established. Other important works were done by Yakov Shirman and his pupils in the field of Adaptive Signal Processing. The theory of radar-system adaptation to interferences was created and different kinds of automated interference compensators were invented. Among other directions of this brilliant team it is reasonable to mention rather famous achievements in the field of multistatic passive radar systems.

The achievements of Yakov D. Shirman have been worldwide recognized. He awarded by the Pioneer Award Committee of the IEEE Aerospace and Electronic Systems Society with the citation: "For the independent discovery of matched filtering, adaptive filtering, and high-resolution pulse compression". A number of outstanding textbooks and monographs were published in Russian, Ukrainian, German, and English in different countries.

Fundamental contribution to antenna theory [9] was also done in VIRTA.

Another important school on radar signal processing was created by S.E. Falkovich in KhAI [10]. Its main scientific direction was the development of the statistical decision theory, estimation and filtering. The novelty of the developed approach at the time was: first, that the research and the results obtained previously for processes (time functions) extend to electromagnetic fields (function of time and spatial coordinates), which are the primary sources of information; second, developing a systematic approach to the problem of optimizing the radar system, when by solving the optimization problem of spatial-temporal processing of the observed fields with specific quality criteria (usually in the Bayesian interpretation) the processing algorithm, the structure of the whole system and the encoding method information carrier are synthesized. The monograph by S.E. Falkovich "Estimation of signal parameters" (1970) where he systematized the issues of space-time processing became a reference book of many experts in the field. Actually, it was a beginning of the statistical theory of measuring space-time radio-engineering systems.

During that period some interesting research and design works were done in NAU particularly in the field of meteorological radar for flight safety [33] and development of stable algorithms for signal processing [34].

VI. Radar in the Independent Ukraine

The works in Ukraine since 1991 were characterized by a sharp weakening of the budget funding for science. A lot of powerful scientific centers, especially military ones were gradually disbanded or combined (including ARTA). Some radar experts from former ARTA started to work in universities, in particular in Kozhedub Kharkov University of Air Forces (KhUAF) and Kharkov National University of Radioelectronics (KhNURE). Contractual relations with Russia were almost terminated. Electronic and radio-engineering industry also seriously suffered. The result was a noticeable reduction of both theoretical and especially applied works. However an important advantage of new situation was a dramatic increase of international projects and relationships. Though a lot of highly qualified and, especially, talented young researches were invited to work abroad, the researches in the field of radar, of course, are continued in basic Ukrainian universities, research institutions, and some industrial enterprises.

Nowadays, not big but rather strong radar groups work in different institutions in Ukraine. Some internationally recognized examples are following.

The Institute of Radio Astronomy of the National Academy of Sciences of Ukraine is involved in the development of various types of radars, including meteorological, search and tracking, surveillance, and SAR systems. Their Ka-band meteorological radars are probably the most sensitive and effective instruments of this type in the world providing detailed measurements of micro- and macro characteristics of clouds and precipitation [11]. The institute has succeeded in development and production of high-resolution SAR systems capable for effective operation from small aircrafts [12].

The group of scientists at KhNURE has remarkable results in the theory, technology and application of adaptive lattice filters especially to the tasks of non-stationary signal processing as both temporal and space-time processes. Adaptive lattice filters were developed for defense against active, passive (clutter), and combined interferences, space-time resolution, and even for meteorological radar application [13].

Theoretical and experimental researches of radio wave propagation at low-altitude over sea and land in wide frequency band (10 to 140 MHz) were done in the Usikov institute of radiophysics and electronics of the National Academy of Science of Ukraine (IRE NASU). Its influence on the radar detection characteristics and accuracy of radar measurements were studied; recommendations to development of radar systems of different classes were made [14].

In the same institution a group of scientists successfully works in the field of noise radar theory, technology and applications [15].

Another IRE NASU group studies clouds and precipitation, using double frequency radar sounding and active-passive methods. The results allow to improve accuracy of rain intensity estimation and to measure spatial profile of cloud water content [16].

Radar group in NAU has developed analog and digital radar means for dangerous meteorological phenomena detection (theory, algorithms, technology) that were implemented in series of airborne weather radars for Antonov, Tupolev, Ilyushin, and Yakovlev aircrafts (State Prize of Ukraine in 1996). Later Doppler-polarimetric method for meteorological radar was developed jointly with Delft University of Technology [17] and spectral polarimetric approach for remote sensing of natural objects and phenomena [18]. In the field of secondary radar Ukrainian version of TCAS has been developed [19] together with Kiev Research Institute "Buran".

Kharkov Karazin National University has made significant contributions to antenna theory and technique development for radar applications [20], [21]. Theoretical Radiophysics department of the same University contributed considerably to research of scattering on complex objects, RCS measurement, interaction of ultrashort pulses with complex objects, antennas for impulse, wideband, and UWB signals [22]. Another group works on UWB and fractal signals theory and technology [23].

In KhAI, new methods were proposed for: synthetic aperture imaging the earth's surface; subsurface mapping techniques; radar mapping of the surface relief with multibeam and multi-frequency synthetic aperture radar; statistical optimization of space-time signal processing thermal self-radiation of various objects and natural environments in broadband and UWB passive radar systems with aperture synthesis [24]. Another group of KhAI sufficiently contributed into the theory and practice of robust locally adaptive processing of multichannel (multi-frequency, dual-polarization) radar images. Essential results have been obtained in automation of data processing including noise parameter blind estimation, parameter setting for loss compression and filtering, classification and quality estimation [25].

A scientific school in the field of secondary emission simulation for different radar objects including ground and aerial (ballistic and aerodynamic) objects including those designed around Stealth technology, subsurface objects (antitank and antipersonnel mines) works in KhUAF [26]. They solve also some problems in antenna theory.

There were a lot of industrial enterprises involved in radar development and production in Ukraine. Nowadays many of huge institutions disintegrated but some new small ones have been created. We can indicate some industrial enterprises that are working in radar field today. Among them:

State Enterprise “Scientific and Production Complex “Iskra” located in Zaporizhzhia develops and produces a number of modern radar systems including those equipped with adaptive phase arrays for military and civilian applications [27].

Joint Stock Company “Kiev Radar Plant” is specialized in manufacture of modern radar and radio-navigation and other electronic equipment particularly for airplanes and helicopters. It provides all stages of radar manufacturing including the full production cycle of the printed circuit boards from the foil-clad dielectrics as multilayer printed circuit boards of the 5th class of difficulty for new generation radio-electronic equipment [28]. In particular, here is manufacture of the family of airborne weather radars developed at the Kiev Research Institute “Buran” who among other radar production has also developed and produced (by the order) the original aircraft collision avoidance system TCAS-2 [19].

Joint Stock Company HC "Ukrspetstechnika" located in Kiev [29]. Main its products are different kinds of Radars, Automatic control systems, Data systems, System integration, Means and integrated systems of data protection and others. HC "Ukrspetstechnika" is involved in upgrade and overhaul projects of air defense radars.

KVANT-RADIOLOKATSIIA Radar System Research Institute is situated in Kiev [30]. It develops and produces radars and radar components. The basic specialization is marine and submarine systems as well as shipborne radar navigational equipment, primary surveillance radar, distance measuring equipment (DME) and other.

As an example of small enterprise, the Transient Technologies LLC is an innovative privat company based in Kiev [31]. It has been engaged in scientific researches, development and production of ground penetrating radars systems and technologies. A contribution to UWB technology in particular for GPR and TWS applications has been done [32].

Another successful relatively small company is RADIONIX Ltd also located in Kiev. The company is involved in Radar system design, production, service and support.

The international relations of Ukrainian scientists with colleagues all over the world increased unprecedentedly. Nowadays international projects and grants became in fact the main source of financing science in Ukraine. Ukrainian researchers participate actively in basic international conferences in different countries. Moreover, several international conferences related to radar that are organized in Ukraine became rather famous and popular among the world radar community. Among them: Millimeter and Sub-Millimeter Waves (MSMW) symposium, IEEE Microwaves, Radar and Remote Sensing (MRRS) symposium, international conference on Mathematical Methods in Electromagnetic Theory (MMET), Ultrawideband and Ultrashort Impulse Signals (UWBUSIS) symposium, International Conference on Antenna Theory and Techniques (ICATT) and some others.

VII. Conclusion

This paper has clearly shown the basic contribution of Ukrainian scientists and institutions located in Ukraine into the development of radar. This contribution is really significant. One can conclude that from the very beginning to nowadays the radar was and still stays the area of great interest in Ukraine. Ukraine has highly qualified experts in different branches of radar, talented young scientists and students who have potential for further development of radar in Ukraine and worldwide, participating in the international projects. Ukrainian radar industry needs for investment of capital and can quickly be restored and developed.

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This article does not claim complete coverage of advances in radar, which is actually much richer, but just suggests some milestones in the development of radar in Ukraine, known to the author, who is solely responsible for its content.

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